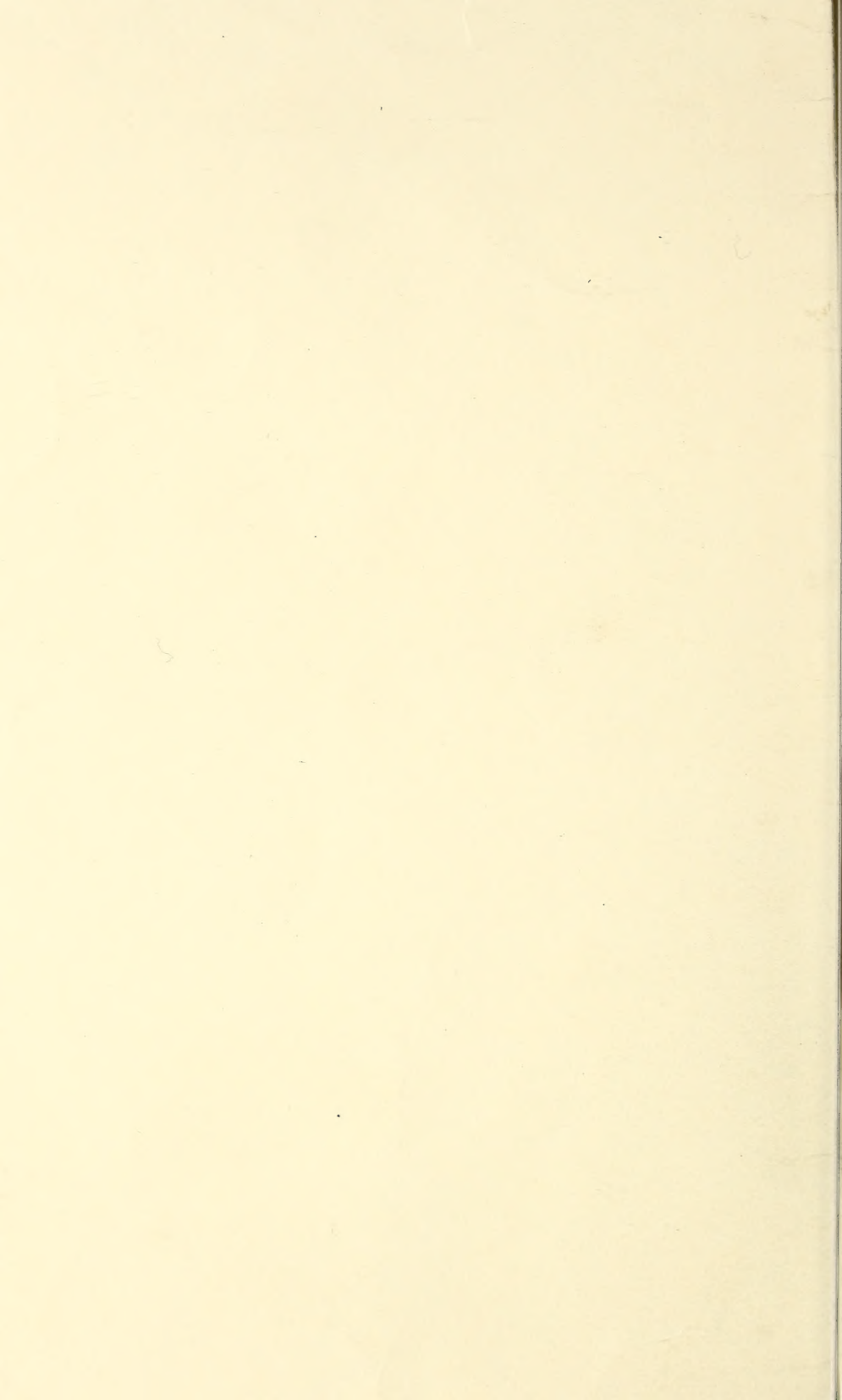
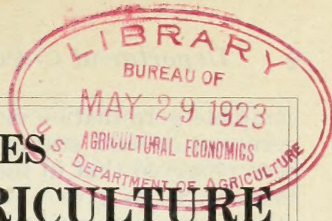


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FROST RESISTANCE IN FLAX.

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INTRODUCTION.

A study of frost injury in flax is important to the breeder because it is best to plant flax early in the spring, and at this time frost injury is often quite severe. The early seeding of flax gives it a number of advantages. It can compete with weeds and disease organisms more successfully and is less susceptible to injury from drought or lodging. Flax will grow at a lower temperature than most weeds, and early seeding gives it a head start so that it can shade out the weeds. The high soil temperatures of July and August favor the development of flax wilt and flax rust. The stems of late-seeded flax are more succulent at this time than those of early-seeded flax, and hence the former are more susceptible to the attack of fungi. Under greenhouse conditions flax is not infected with flax wilt below 59° F., although flax thrives well at 55° F. The optimum range of temperature for the growth of *Fusarium lini* Bolley, the organism that causes flax wilt, is 79° to 82° F., and it may be regarded as a high-temperature organism.¹ Early-seeded flax can take advantage of the spring rains and make a steady growth during cool weather that gives stiffness to the stems; late-seeded flax may either be stunted by drought or a very rapid growth induced by heavy rainstorms and hot weather may render it liable to lodging.

Field observations have given indications that there are varietal differences in the ability of flax to resist frost. Flax may be injured by cold weather immediately after seeding that interferes with

¹Tisdale, W. H. The relation of temperature to the growth and infecting power of *Fusarium lini*. In *Phytopathology*, v. 7, p. 356-360, 1 fig., pl. 11. 1917.

complete germination or by a severe frost that strikes the flax after germination and stunts the growth or depletes the stand. It has been observed that in the experimental plats at East Lansing, Mich., some varieties give a very poor stand when planted early, while others germinate well whether planted early or late. Several agronomists have noted varietal differences in flax on frost resistance, but there does not appear to have been any attempt to take advantage of this and select for increased resistance. C. H. Clark, formerly of the Office of Cereal Investigations, Bureau of Plant Industry, and H. Hunter² both noted that some varieties of flax were injured more than others by frost during early growth.

THE TEMPERATURE RANGE FOR FROST TESTS WITH FLAX.

Representative groups of flax were chosen for tests, with the object of determining the extent of the differences in frost injury that might be present and if possible the nature of this injury in flax. The tests included imported fiber flaxes, several seed-flax selections, two commercial varieties of fiber flax, and a group of tall fiber-flax selections developed by the Office of Fiber Investigations. Seven tests were conducted in all, two in the fall of 1921, which were planted out of doors, and five in the spring, in which the flax was germinated in boxes of sand and then exposed out of doors.

TABLE I.—*Frost-resistance tests with flax.*

[The 1921 test plats were covered with 1 foot of snow, which melted after two weeks, leaving the flax uninjured.]

Season and test.	Date exposed.	Number of days.		Minimum temperatures (° F.).		Percentage of plants that survived.	Remarks.
		After seeding when exposed.	Period of exposure.	Noninjurious.	Injurious.		
Fall of 1921:							
No. 1.....	Nov. 18	52	8	27	24 to 23....	0 to 37.5..	Second leaves formed when frosted.
No. 2.....	Dec. 1	42	8	27	24 to 23....	1 to 12.5..	In cotyledon stage when frosted.
Spring of 1922:							
No. 1.....	Feb. 21	6	6	39	18.....	0 to 15....	Soil very cold when seeded. Strong wind, accompanied by freezing temperatures.
No. 2.....	Mar. 6	7	2	34	21.....	17 to 54....	
No. 3.....	Mar. 11	10	7	26	21 to 19....	0 to 7....	
No. 4.....	Mar. 22	4	10	26	25.....	21 to 92....	Heavy sleet on Mar. 31. Seedlings weighted down with ice.
No. 5.....	Mar. 30	5	4	26	25.....	8 to 48....	

In spite of a great variety of weather conditions, such as freezing temperatures from 19° to 32° F., accompanied at times by high winds or heavy sleet and snow storms, the effect on the flax was fairly uniform. In no case did a temperature of 26° F. or above cause injury (see Table 1), and a temperature of 25° F. or below

² Hunter, H. Improvement of the flax crop by propagation from selected plants. *In* Dept. Agr. and Tech. Instr. Ireland Jour., v. 15, p. 237-246, 1 fig. on pl. 1915.

always resulted in pronounced injury. A temperature of 19° F. killed all except 7 per cent of the most resistant variety. A temperature of 25° F. may not kill more than 10 to 25 per cent of the stand. For these tests a temperature range of 21° to 24° F. appears to be best.

THE EXTERNAL NATURE OF FROST INJURY.

Frost first attacks the flax seedling about 2 centimeters above the ground line, where a slight ring of purple develops in the hypocotyl (see Fig. 1.) When the injury is more pronounced a slight constric-

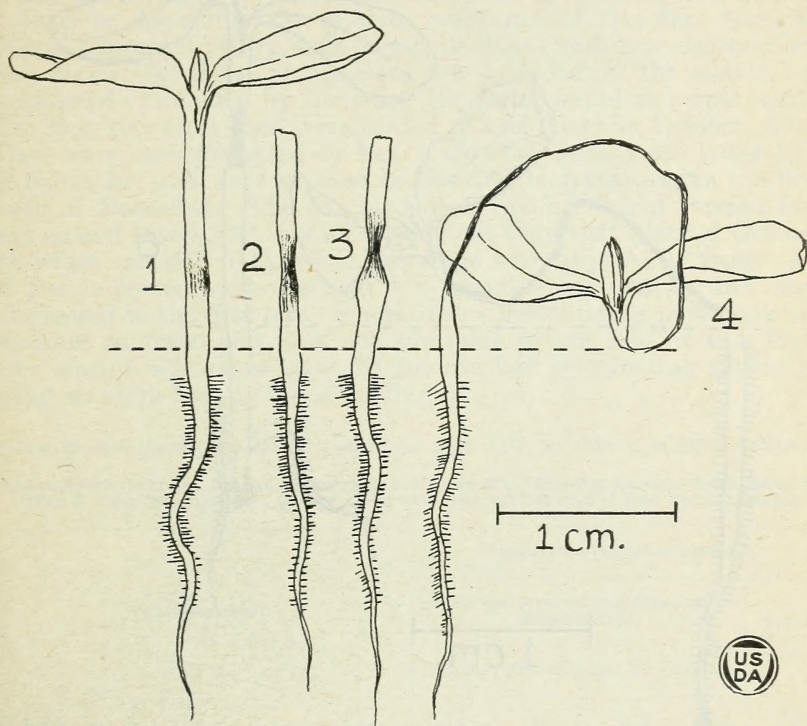


FIG. 1.—Frost injury to flax seedlings: 1, Entire plant normal except for slight purple discolorations on the hypocotyl; 2, purple band deepens; the hypocotyl is slightly constricted; 3, the band of purple is still darker; a deep constriction of the hypocotyl is accompanied by a swelling directly beneath; 4, the tissue of the hypocotyl has been destroyed; the cotyledons and the root remain apparently normal one week after the frost injury.

tion occurs at this point. If the injury is severe the hypocotyl will swell below the point of constriction and the purple band will become quite dark. Unless the temperature falls below 19° F. or below the flax plant's power of resistance the frost only injures the roots or cotyledons indirectly. The extreme condition (see fig. 1) occurs when the entire hypocotyl is shriveled by the frost. The cotyledons and roots may remain healthy and apparently in good growing condition for a week to 10 days after this occurs, provided they are protected from additional freezing. The root system is at last apparently starved as a result of the girdling of the hypo-

cotyl. When this happens the roots can no longer supply the cotyledons with water and they become withered. Frequently the flax plant appears normal above the ground line except for a slight purple band and constriction in the hypocotyl, but when the plant is pulled up the taproot is found to be destroyed by fungi (see Fig. 2). The power of resistance of the roots to fungi appeared to have been lowered by a partial starvation as a result of the slight constriction

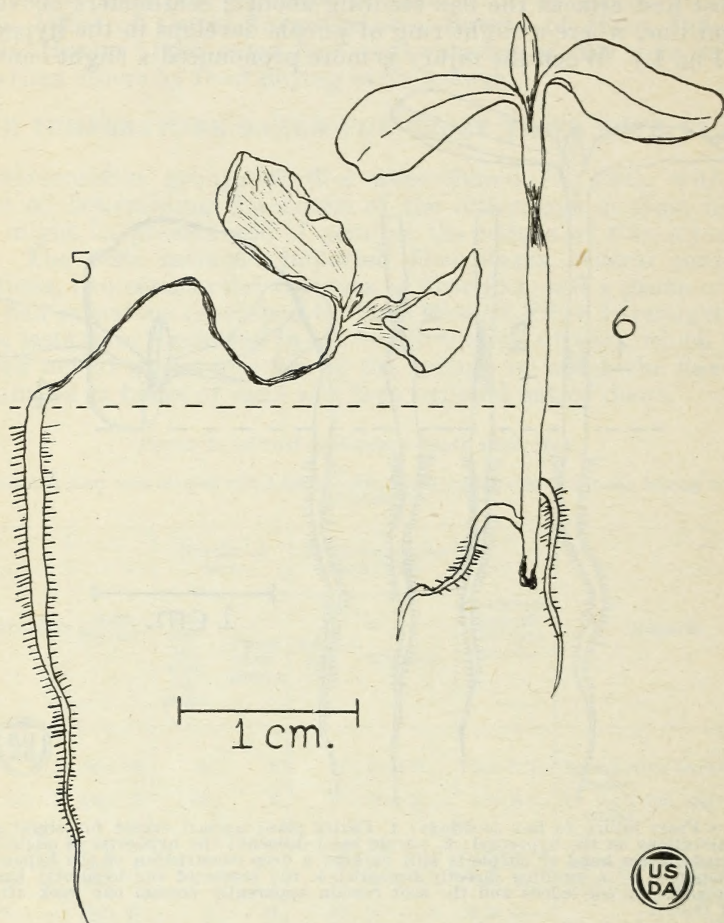


FIG. 2.—Frost injury to flax seedlings: 5, The tissue of both cotyledons and hypocotyls has been destroyed. Note the shriveled condition. The root is apparently uninjured. 6, One week after frost injury. Part of the seedling above ground is normal except for the purple band and the constriction of the hypocotyl. The root tissue has been partly destroyed by the fungus.

of the hypocotyl. The same varieties of flax were not attacked by fungi in the germination boxes unless exposed to frost. These observations were made use of later in the process of selecting frost-resistant plants; only those flax plants that survived the frost tests with healthy roots and without any trace of purple or constriction of the hypocotyl were transplanted to breeding plats for increased resistance.

VARIETAL DIFFERENCES IN FROST RESISTANCE.

With some selections most of the plants that survived the frost appeared normal except for the purple band and slight constriction, and in other selections the injury to the hypocotyls was much more pronounced. The different kinds of flax varied consistently in the degree of injury from frost. White Blossom Dutch was usually injured so that the entire hypocotyl of every plant was withered, whereas hypocotyl injury could scarcely be detected in Saginaw or Blue Blossom Dutch.

The percentages of plants that survived the frosts were used as a basis to determine the relative resistance of the flax varieties. Where hypocotyl injury, such as purple discoloration or constriction, was noticeable, those plants were not included in the counts but considered eliminated by the frost, for death would as a rule result. The first two frost tests were seeded out of doors in October, 1921. They were both protected by heavy snowfall during the latter half of November and were exposed to freezing temperatures in the first week of December. The flax seeded on October 8 had formed first and second leaves and was more resistant than that planted October 20, which was still in the cotyledon stage when injured by frost. All of the imported seeds were of low germinating quality and were eliminated in the first test. Seeds of low germinating power are not resistant to frost, and it is not advisable to use seed of this kind, even though allowance be made for the low germinating power by using an extra heavy rate of seeding.

TABLE 2.—Comparison of frost resistance and wilt resistance in flax varieties.

[Unless otherwise indicated, the flax varieties in this table are all tall fiber-flax selections developed by the Office of Fiber Investigations. All seeds used were from the 1921 crop at East Lansing, Mich.]

Varieties planted.	Comparative resistance (per cent).				Resistance to wilt.
	Stands that survived frost injury on the dates observed.				
	Dec. 8.	Feb. 27.	Mar. 18.	Average.	
No. 21003.....	12.5	23.5	5.50	14.04	170
Blue Blossom Dutch (commercial fiber flax).....	12.6	9.47	7.55	9.87	25
NDR No. 114 (wilt-resistant seed flax, N. Dak. Agr. College).....	12.5	9.23	5.68	9.14	70
Saginaw.....	12.5	9.18	3.75	8.44	83
No. 21014.....	12.5	9.3	3.33	8.38	80
M 91-1 (seed flax, Minn. Agr. Expt. Station).....	8.6	7.03	5.00	6.88	84
No. 21010.....	7.6	11.5	1.50	6.87	85
No. 21029.....	9.0	7.16	0	5.58	39
No. 21027.....	4.1	12.45	0	5.52	17
No. 21023.....	9.3	6.08	0	5.13	62.3
No. 21004.....		7.95	0	3.97	33
M 74-1 (seed flax, Minn. Agr. Expt. Station).....	3.34	1.45	2.15	2.31	82
White Blossom Dutch (commercial fiber flax).....	0	6.04	0	2.01	0
No. 21025.....	1.6	2.63	0	1.41	42
No. 21012.....	0.7	1.48	1.09	1.09	38

¹ Estimated from seedlings made in 1915 and 1919 on infected soil in Michigan. The rest of the data on wilt resistance is largely taken from the notes of J. C. Brinsmade, jr., and W. E. Brentzel, of the Office of Cereal Investigations, on 1920 and 1921 seedlings at Mandan and Fargo, N. Dak.

The White Blossom Dutch flax, which is so severely injured by frost, made a strong contrast in percentage of survivals with resistant types. Out of 300 White Blossom Dutch plants that emerged in the

second frost test none survived, although 12.5 per cent of the plants in the rows of Blue Blossom Dutch, Saginaw, and two other flaxes survived. The first two spring tests in which the same varieties and selections were duplicated confirmed these results, and it is concluded that the frost resistance varies with different flaxes and that these differences are sufficiently marked to warrant further selection for increased resistance. In Table 2 the flaxes are arranged in accordance with their rank in frost resistance. At the top of the list is selection No. 21003, followed by Blue Blossom Dutch, a short commercial

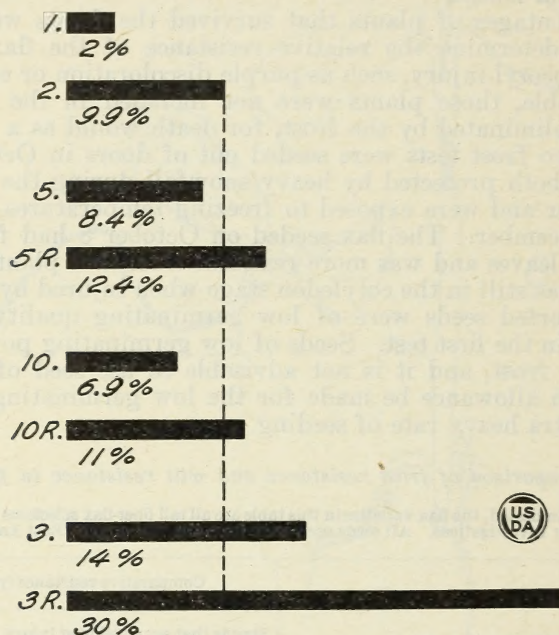


FIG. 3.—Diagram showing the improvement secured by selecting for increased frost resistance. Saginaw, a tall fiber-flax selection, is several times as resistant as White Blossom Dutch. A reselection from Fiber Investigations No. 21003 is 3 times as resistant as Blue Blossom Dutch and 15 times as resistant as White Blossom Dutch. The percentages of plants that survived frost are specified. 1, White Blossom Dutch, a commercial fiber flax; 2, Blue Blossom Dutch, a commercial fiber flax; 5, Saginaw, a tall fiber-flax selection; 5R, Reselection from Saginaw, No. 1805-21; 10, Selection 21010, a tall fiber-flax selection; 10R, Reselection from 21010; 3, Selection 21003, a tall fiber-flax selection; 3R, Reselection from 21003, No. 2203-18.

fiber flax. North Dakota Resistant No. 114, Saginaw, and selection No. 21014 follow directly behind and almost in the same class as Blue Blossom Dutch. The percentages of survivals tally very well for the most part, so that the order or rank in resistance would not change very much, even though the data from only one frost test were to be used. While it is not safe to generalize on the relation between frost resistance and flax wilt from observations on only 15 kinds of flax, it is evident that as a rule the flaxes that are most resistant to frost are also strongly resistant to flax wilt. Out of the eight flaxes most resistant to frost, all except one are strongly resistant to wilt, and out of the seven flaxes most susceptible to frost, only one is strongly resistant to wilt and one partly resistant to wilt.

Three more tests were conducted in the spring of 1922 with reselections from the more resistant of the tall fiber-flax selections. The parent stocks of seed and the two commercial fiber-flax selections were included for the sake of comparison. The accompanying diagram (Fig. 3) shows that in each case improvement over the parent stock has been secured. One selection from Fiber Investigations No. 21003 was three times as resistant as Blue Blossom Dutch and nine times as resistant as White Blossom Dutch. The data on the reselections offer additional confirmation that frost resistance is a power that varies with different flaxes and is inherited from one progeny to the

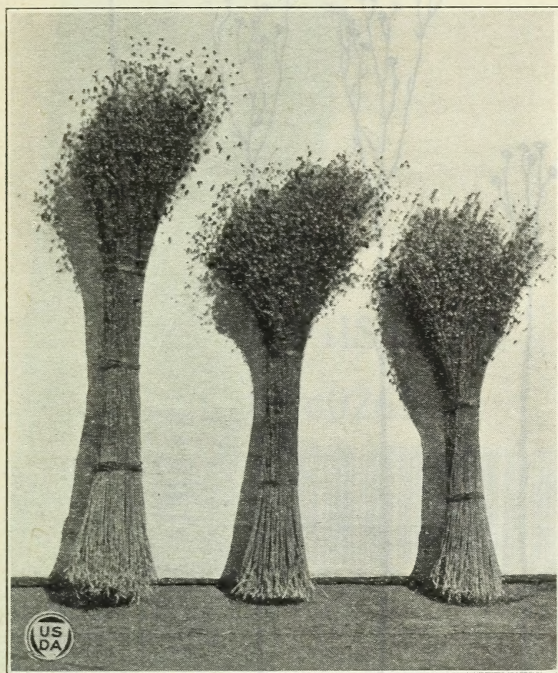


FIG. 4.—Frost resistance in flax. A comparison between Saginaw and unselected fiber flax. From right to left: Blue Blossom Dutch, 63 centimeters total height, resistant to frost; White Blossom Dutch, 69 centimeters total height, very susceptible to frost; and Saginaw, 82 centimeters total height, resistant to frost. (See Fig. 5, showing drawings of individual plants.)

next in a single plant selection. The reselections from Saginaw are also more resistant to frost injury than Blue Blossom Dutch (Figs. 4 and 5).

CONCLUSIONS.

The temperature range for frost-resistance tests with flax is 21° to 24° F.

Frost injury is first noticeable in the flax hypocotyl, and unless the temperature falls below the range of frost resistance the cotyledons and root system are affected only indirectly.

Seeds of low germinating quality produce plants very susceptible to frost.

Tests conducted on 15 flax varieties and selections indicate that most flaxes resistant to frost are also strongly resistant to flax wilt.

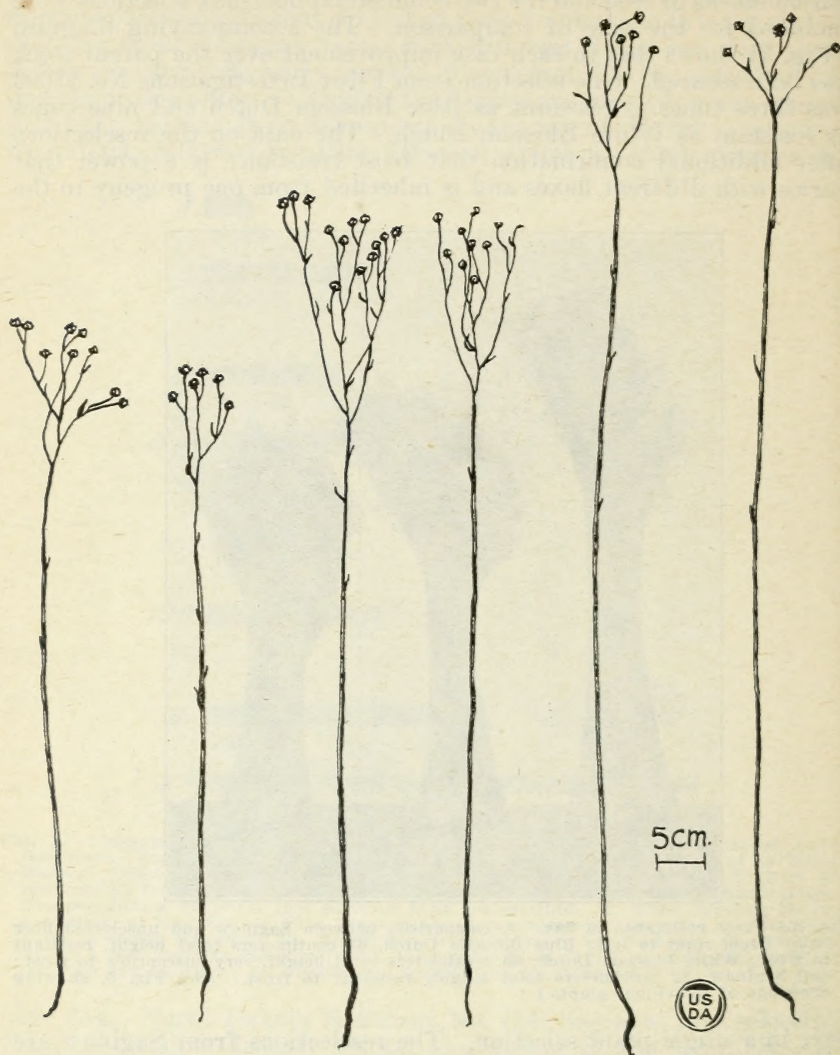


FIG. 5.—Frost resistance in flax. A comparison between Saginaw and unselected fiber flax. Typical plants from the bundles in Figure 4 are taken for this comparison. In the center are two plants of White Blossom Dutch, a variety susceptible to frost, with a panicle 20 centimeters long and coarse stems 54 centimeters to the first branch. On the right is Saginaw, resistant to frost, with a panicle 13 centimeters long and fine long stems, 78 centimeters to the first branch. On the left are two plants of Blue Blossom Dutch, resistant to frost, with a panicle 11 centimeters long and fine stems, 47 centimeters to the first branch.

Flax varieties vary in their ability to resist frost, and marked improvement may be secured by making selections for increased resistance.

